



Technical Note

91

DETERMINATION OF THE K FLUORESCENCE YIELD OF ARGON BY PROPORTIONAL-COUNTER SPECTROMETRY



U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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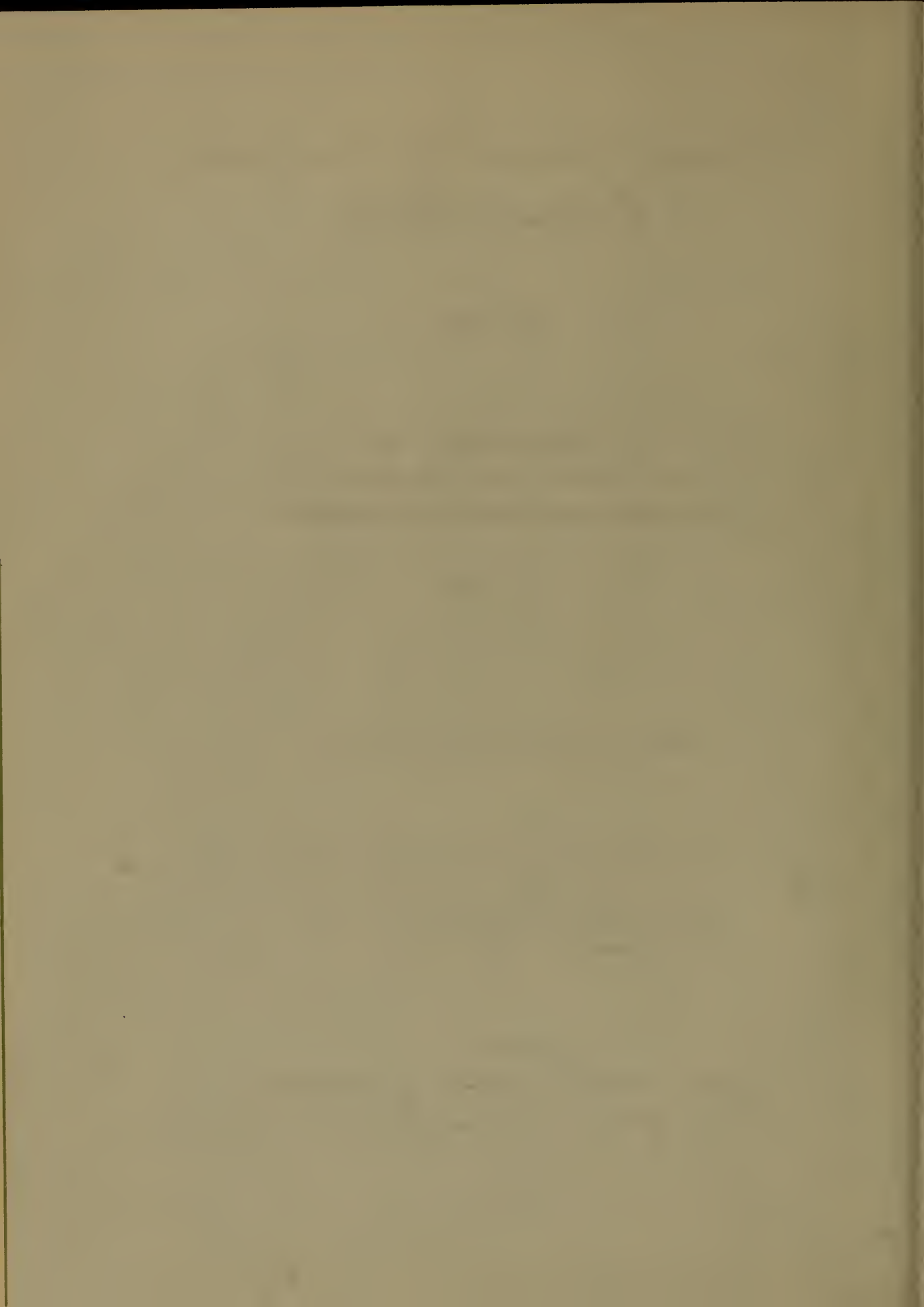
Claire Godeau

The work described in this paper was carried out at the National Bureau of Standards, Washington, D. C., U.S.A.

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Determination of the K Fluorescence Yield of Argon by Proportional-Counter Spectrometry

Claire Godeau¹

A proportional counter spectrometer designed for investigation of low energy particles has been used for the determination of the K fluorescence yield of argon.

X-rays following K capture in iron-55 were used as a source for excitation of the argon atom and the spectrum was measured. The K fluorescence yield ω_K was deduced from the comparison of the two peaks shown in the spectrum and corrections were made, taking into account photoelectric absorption in outer shells and reabsorption of secondary X-rays in the counter.

The fluorescence yield ω_K of argon was found to be 0.087 ± 0.007 .

1. Introduction

A proportional-counter spectrometer has been designed which can be used for the investigation of low-energy particles. It has been used for the determination of the K fluorescence yield of argon.

Different authors [1-6] have shown that a proportional-counter device is suitable for that purpose.

2. The Proportional-Counter Description

The counter, a sketch of which is shown in figure 1, is a brass cylinder with an inside aluminum lining. It is 12" long and 3" in diameter. The central electrode made of tungsten wire (2 mils in diameter) is held by Kovar seals, providing the electrical insulation

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from the external electrode. The counter has an 0.5-mil mylar window which can be easily removed. The vacuum seal at the window is provided by an O-ring held in position by means of a brass ring (figure 1-a). The filling gas is a mixture of argon and methane (90% argon, 10% methane). The counter must be operated at pressures such that the energy of the electron is completely absorbed in the sensitive volume of the counter. For the measurement of the K fluorescence yield of argon, work was carried out at pressures lower than atmospheric and the cap shown in figure 1-b was used in order to have the same pressure on both sides of the mylar window.

3. Electronic Equipment

This is shown in block diagram in figure 2. The pulse due to the event in the sensitive volume of the counter is amplified in a non-overloading linear amplifier and then presented to a single channel pulse-height analyzer. The number of events per voltage interval is determined by a scaler. In order to avoid the high impedance at the counter output, a cathode follower is mounted directly on the counter.

4. Calibration of the Spectrometer

Energy calibration of the counter was performed by measuring the pulse height induced by monoenergetic incident radiation of known energy. A good source of monoenergetic radiation is provided by the X-rays following electron capture in certain nuclides (iron-55, zinc-65 and barium-133). The process can be described as follows: After K absorption the iron-55 nucleus becomes a manganese-55 nucleus and an X-ray characteristic of manganese is emitted. This X-ray is absorbed in the filling gas of the counter by photoelectric process. A K electron of argon is thus knocked out of the argon atom and emitted with an energy equal to the incident energy minus the binding energy of a K electron of argon. There is now a vacancy in the K shell of the argon atom which is filled by an electron from an outer shell giving rise to the emission of an X-ray characteristic of argon. This X-ray can either escape, or be absorbed in the counter according to the Auger effect. If it escapes, the energy spent in the counter is the energy of the K photoelectron only, but in case of Auger absorption the total incident energy is spent in the counter. One can thus expect two peaks in the spectrum obtained with iron-55 source (figure 3), the low energy peak being due to K photoelectrons only and the high energy peak being due to K photoelectrons plus Auger electrons.

In the case of iron-55 the X-ray characteristic of manganese has an energy of 5.9 kev. The binding energy of the argon K electron is 3.2 kev so that the low energy peak in the spectrum represents $5.9 - 3.2 = 2.7$ kev while the high energy peak corresponds to 5.9 kev. Both these energies are used as calibration points.

A similar process for zinc-65 gives two more points for the calibration curve. The situation with barium-133 is somewhat different because of the very low photoelectric cross section for cesium X-rays in argon. The barium source was accordingly placed inside the counter and the barium Auger electrons were detected and used to obtain a further point on the calibration curve.

These points have been used to establish the calibration curve of the proportional-counter spectrometer between 0 and 26 kev. By taking into account the amplifier gain and the base-line vernier calibration of the pulse-height analyzer, the pulse height in millivolts at the output of the counter can be plotted against the energy.

Figure 4 shows the curve obtained. One can draw a straight line for the low energy end, but the 26-kev point is somewhat off this line. The calibration curve is however linear up to and slightly beyond the characteristic X-ray energy of iron-55 which was used in the determination of the fluorescence yield.

5. Resolution of the Spectrometer

The resolution was measured for the different calibration points by measuring the width of the peaks at half maximum. The values obtained for 2.7 kev and 5.9 kev are respectively 27% and 18%. They are similar to those obtained by Bertolini, Bisi and Zappa [5] for the same type of counter.

As previously described, when external radiation of a certain range of energy falls upon an argon atom, a K-shell photoelectron is emitted followed by an Auger electron or an X-ray characteristic of argon. In nearly all cases the X-ray will escape. We thus obtain two peaks (figure 3), a high energy peak, corresponding to absorption of the argon K-shell photoelectron and Auger electron, and a low energy peak known as the escape peak, corresponding to absorption of the argon K-shell electron and escape of the argon X-ray.

6. Fluorescence Yield

The fluorescence yield ω_K is defined as the probability that a K-shell vacancy results in X-ray emission.

7. Determination of the Fluorescence Yield

Considering the spectra obtained, one can very easily deduce the fluorescence yield from the intensities of the two peaks, assuming that the process is the one described above (we will see later that corrections must be applied). If I_1 is the intensity of the low-energy peak, and I_2 is the intensity of the high-energy peak, the fluorescence

yield ω_k is determined by $I_1/(I_1 + I_2)$, since I_1 is the number of K photoelectrons followed by non-measured X-radiations, and I_2 is the number of K photoelectrons followed by Auger electrons.

8. Corrections

Two major corrections have to be made to the data to obtain the fluorescence yield due to the fact that:

- 1) The incident electromagnetic radiation can produce photoelectrons from the L and M shells of the argon atom. These photoelectrons cannot be resolved from the high-energy peak;
- 2) The secondary X-rays can be reabsorbed in the counter by a photoelectric process in another atom of argon. In that case, the total incident energy will again be absorbed in the counter but not by the Auger effect, and the intensity of the high-energy peak will be unduly high.

8.1. First Correction

According to Bertolini, Bisi and Zappa [5], the percentage of atoms ionized in the outer shells can be calculated by taking into account the photoelectric absorption coefficient of the various shells, τ_k , τ_l , τ_m . The relation between the real fluorescence yield ω_k and the fluorescence yield ω'_k , modified by absorption in outer shells, is

$$\omega_k = \left(1 + \frac{\tau_l}{\tau_k}\right) \frac{\omega'_k}{1 + \frac{\tau_l}{\tau_k} \omega'_k} \quad \text{---} \quad (1)$$

the contribution of the M shell being negligible. According to [7] the ratio $\frac{\tau_l}{\tau_k}$ for argon is 0.071.

8.2. Second Correction

Calculation of the reabsorption of a secondary X-ray in the volume of the counter is very difficult, involving a double volume integration, but this effect can be evaluated in the following manner: At pressure zero, it is normal to assume that there is no reabsorption. If one can plot the ratio $I_1/(I_1 + I_2)$ against the pressure, the value extrapolated to zero pressure gives the pressure correction for the fluorescence yield ω'_k .

9. Results

The proportional counter described above was used at different pressures. The pressure was made the same on both sides of the mylar window in order to avoid breaking the window (figure 1-b). The iron-55 source was mounted on the window. The gas (90% argon - 10% methane) circulated from the tank through the cap placed on top of the window before passing through the counter itself. A vacuum pump connected on the other side of the counter allowed the pressure, which was read on a mercury manometer, to be lowered. The flow rate was regulated by a sylphon valve and checked with a bubbler. The iron-55 spectrum was measured at pressures ranging from 0.53 atmosphere to 1.03 atmosphere.

The ratio $I_1/(I_1 + I_2)$ was calculated for each spectrum, I_1 being the numerical integration of the low-energy peak and I_2 the one for the high-energy peak, the two peaks being resolved after subtraction of the background (figure 3). $I_1/(I_1 + I_2)$ was plotted against the pressure (figure 5).

Extrapolation by least squares to zero pressure was used to draw the most probable straight line passing through these experimental points. The extrapolated value of the fluorescence yield so obtained, taking into account the correction for reabsorption of secondary X-rays, is

$$\omega'_k = 0.082 \pm 0.006$$

The error assigned is the standard deviation of the intercept. The correction for absorption of the primary radiation in the outer shells of the argon atom has to be applied by using formula (1), and the final result obtained for the K fluorescence yield of argon is

$$\omega_k = 0.087 \pm 0.007$$

10. Comparison with Existing Values

ω_k	Method of Measurement	Reference
0.07	Cloud chamber	8
0.149	Cloud chamber	9
0.077	Cloud chamber	10
0.06	Proportional counter spectrometer	1
0.123	Width of X-ray absorption line	11
0.083	Theoretical value	12
0.085	Proportional counter spectrometer	5
0.087	Proportional counter spectrometer	Present measurement

11. Background Measurement

A complete background spectrum was obtained by making a run of measurements without a source and it was used to help interpolate the background in the actual spectra below the peaks. Further checks were made by counting backgrounds beyond the peaks at the end of each spectrum. It was found that errors in background measurements cannot affect the final result by more than $\pm 5\%$.

12. Influence of the Presence of Methane in the Argon

Pure argon cannot be used as a filling gas in the proportional counter because of its having metastable states. One has to add methane and one may wonder how its presence will affect the peaks intensities.

The absorption of primary radiation in methane is much lower than the absorption in argon. The amount of methane in the filling gas being only 10%, one can calculate that the absorption of primary radiation in methane represents only 0.4% of the total absorption.

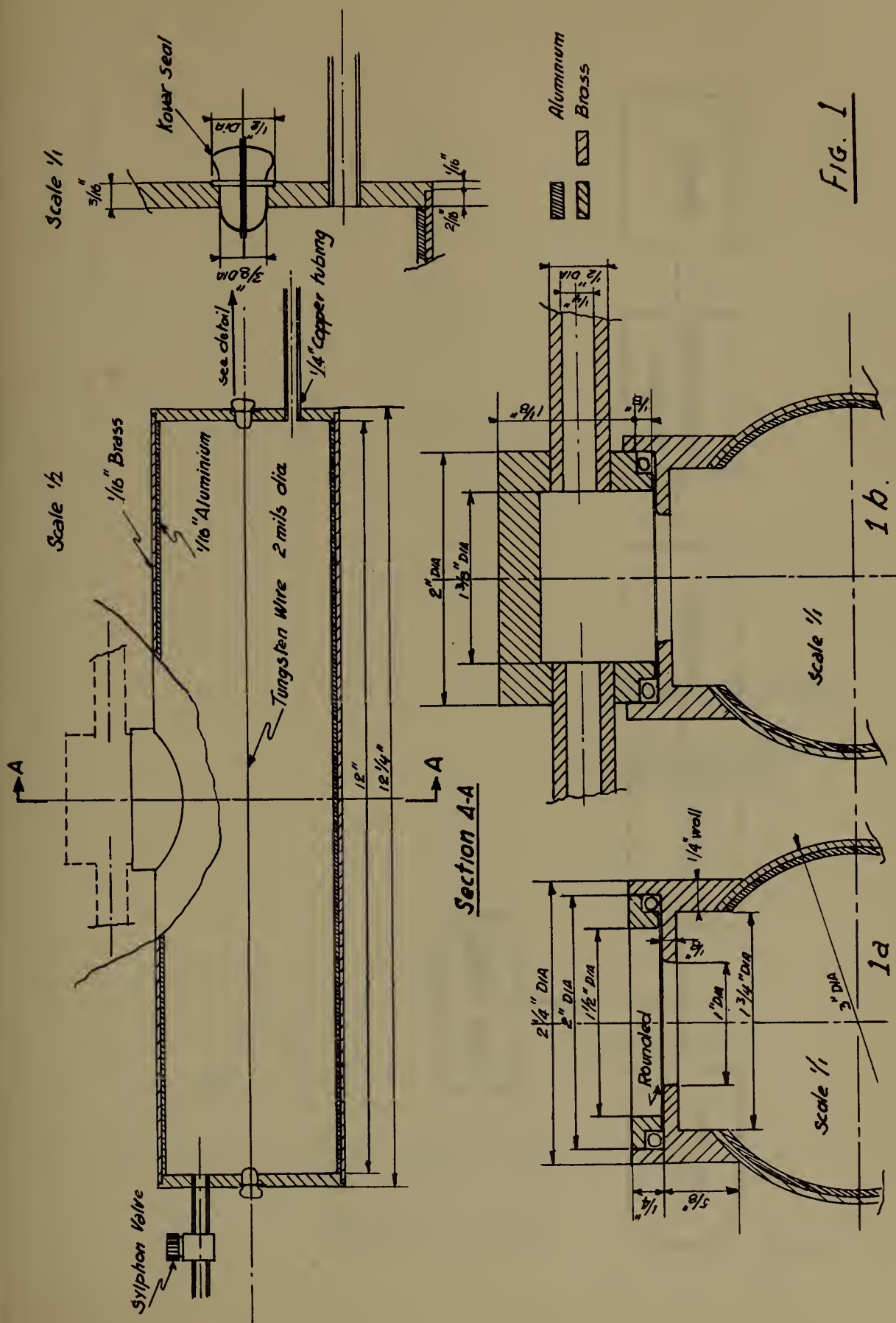
When the primary radiation is absorbed in methane, the energy dissipated in the counter is either the total incident energy, or that energy minus the binding energy of a K electron, in a similar way with argon. The binding energy of a K electron in methane is so small, however, that the two processes cannot be resolved and both appear in the high energy peak of the spectrum. Taking into account the low probability of the absorption in methane and the fact that only the high energy peak, which has the higher intensity, is affected, it is clear that the error on the fluorescence yield can be neglected in comparison with the final error and it can be calculated to be of the order of 0.4%.

Acknowledgments

The author is grateful to Dr. H. H. Seliger and Dr. W. B. Mann for helpful discussions and to Mr. G. W. Randel for help in the construction of the counters.

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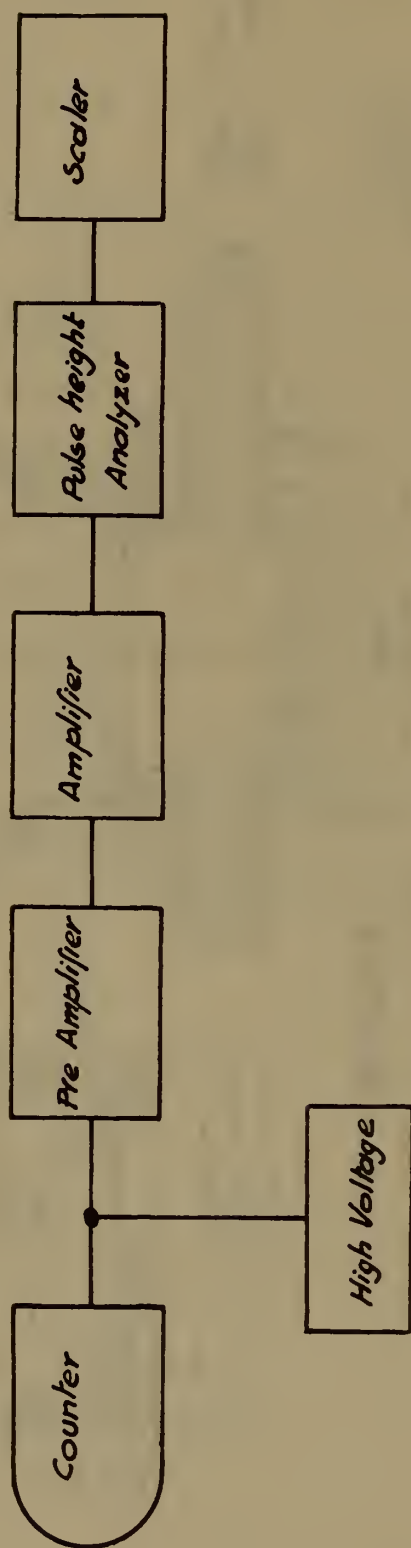
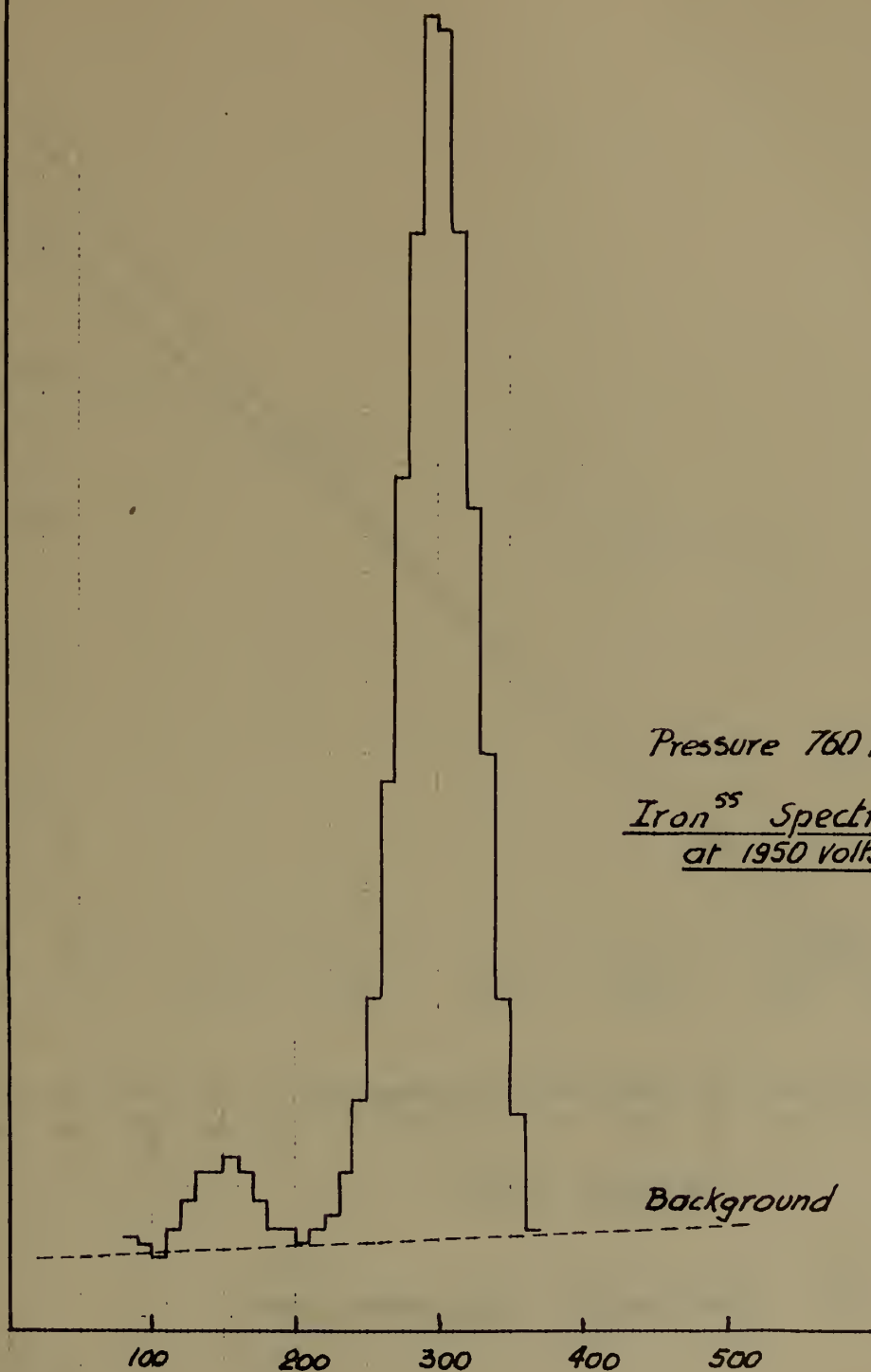


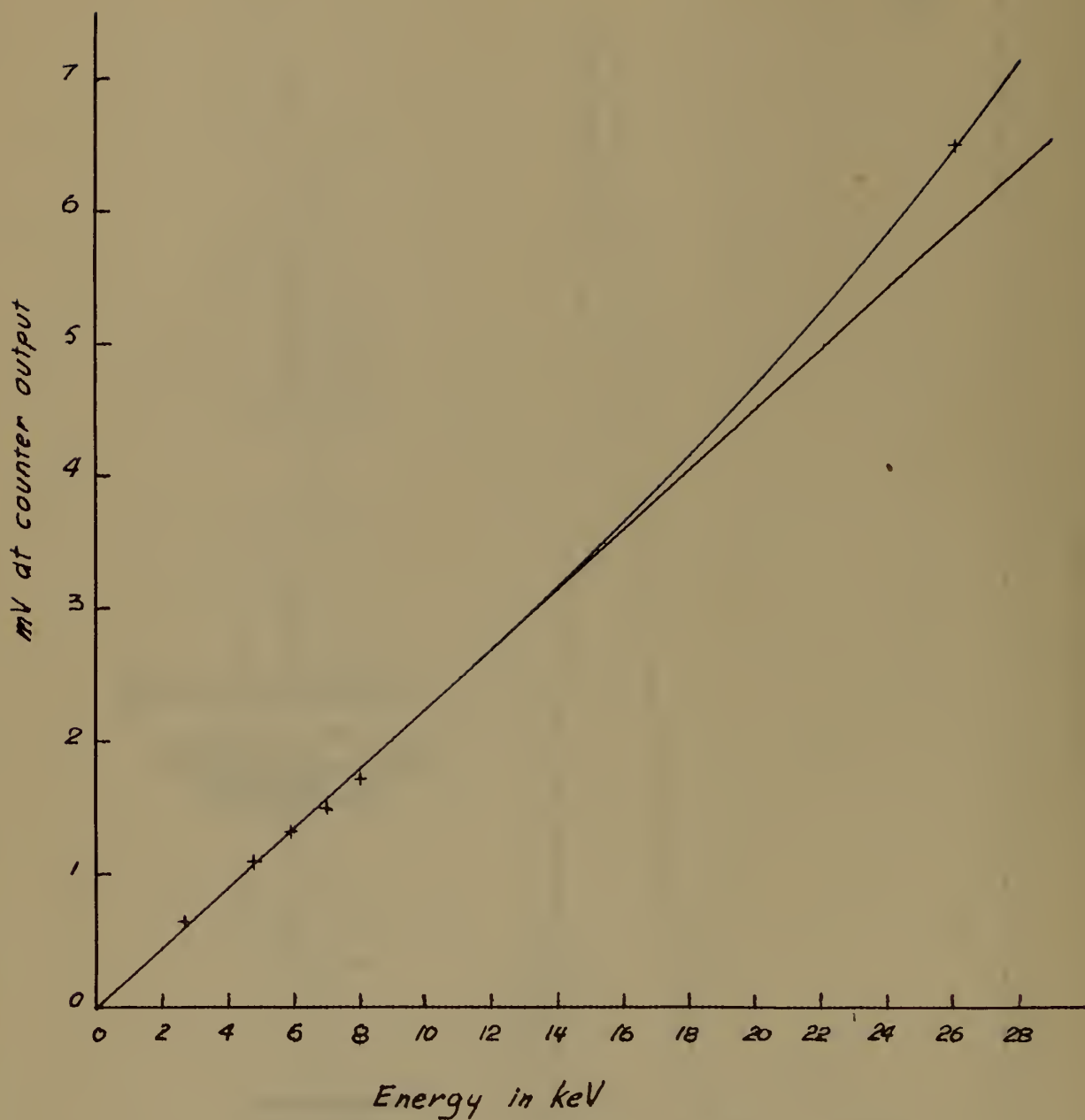
Fig. 2

Counting Rate



Base line vernier

Fig 3



Spectrometer Calibration Curve

Fig 4

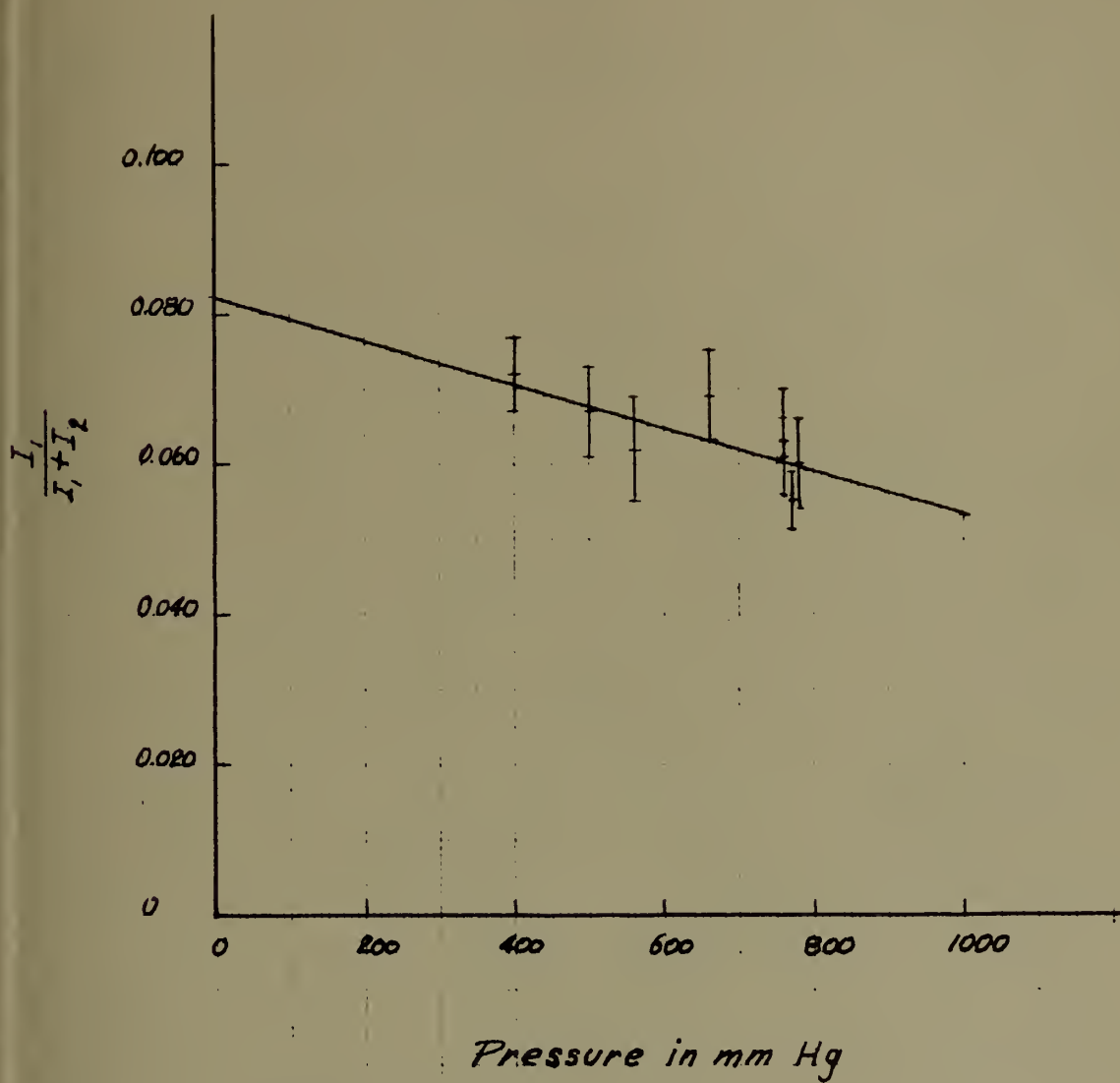


Fig 5

U. S. DEPARTMENT OF COMMERCE

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THE NATIONAL BUREAU OF STANDARDS

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Electrostatics, Resistance and Resistance, Electrochemistry, Electrical Instruments, Magnetic Measurements, Industries.

Metallurgy, Photometry and Colorimetry, Refractometry, Photographic Research, Length, Engineering Metallurgy, Mass and Scale, Volumetry and Density.

Heat, Temperature Physics, Heat Measurements, Cryogenic Physics, Equation of State, Statistical Physics, Radiation Physics, X-ray, Radioactivity, Radiation Theory, High Energy Radiation, Radiological Equipment, Acoustic Instrumentation, Neutron Physics.

Analytical and Inorganic Chemistry, Pure Substances, Spectrochemistry, Solution Chemistry, Analytical Chemistry, Inorganic Chemistry.

Acoustics, Sound, Pressure and Vacuum, Fluid Mechanics, Engineering Mechanics, Rheology, Combustion Controls.

Organic and Fibrous Materials, Rubber, Textiles, Paper, Leather, Testing and Specifications, Polymer Structures, Plastics, Dental Research.

Metallurgy, Thermal Metallurgy, Chemical Metallurgy, Mechanical Metallurgy, Corrosion, Metal Physics.

Mineral Products, Engineering Ceramics, Glass, Refractories, Enameled Metals, Crystal Growth, Physical Properties, Constitution and Microstructure.

Building Research, Structural Engineering, Fire Research, Mechanical Systems, Organic Building Materials, Codes and Safety Standards, Heat Transfer, Inorganic Building Materials.

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Data Processing Systems, Components and Techniques, Digital Circuitry, Digital Systems, Analog Systems, Automation Engineering.

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Instrumentation, Engineering Electronics, Electron Devices, Electronic Instrumentation, Mechanical Instruments, Basic Instrumentation.

Physical Chemistry, Thermochemistry, Surface Chemistry, Organic Chemistry, Molecular Spectroscopy, Reaction Kinetics, Mass Spectrometry, Molecular Structure and Radiation Chemistry.

Units of Weight and Measures.

BOULDER, COLO.

Cryogenic Engineering, Cryogenic Equipment, Cryogenic Processes, Properties of Materials, Gas Liquefaction, Atmospheric Research and Propagation, Low Frequency and Very Low Frequency Research, Ionosphere Research, Prediction Services, Sun-Earth Relationships, Field Engineering, Radio Warning Services.

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Radio Systems, High Frequency and Very High Frequency Research, Modulation Research, Antenna Research, Transmission Systems, Space Telecommunications.

Upper Atmosphere and Space Physics, Upper Atmosphere and Plasma Physics, Ionosphere and Exosphere Studies, Airglow and Aurora, Ionospheric Radio Astronomy.

